PROCEEDINGS OF SCIENCE

Probing the dipole moments of the tau-neutrino at high-energy γe^- and $\gamma\gamma$ collisions: ILC and CLIC

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We obtain limits on the dipole moments of the ν_τ through the reactions $e^+e^- \to e^+\gamma^* e^- \to e^+\tau\bar{\nu}_\tau\nu_e$ and $e^+e^- \to e^+\gamma^*\gamma^* e^- \to e^+\nu_\tau\bar{\nu}_\tau e^-$ at a future high-energy and high-luminosity linear electron positron collider, such as the ILC and CLIC. The limits obtained are of the order of $\mu_{\nu_\tau} \leq 1.44\times 10^{-6}\mu_B$ and $d_{\nu_\tau} \leq 2.78\times 10^{-17}$ $e\,cm$ in the $\gamma^* e^-$ collision mode and of $\mu_{\nu_\tau} \leq 3.4\times 10^{-7}\mu_B$ and $d_{\nu_\tau} \leq 6.56\times 10^{-18}$ $e\,cm$ with the $\gamma^*\gamma^*$ collision mode, improving the existing limits.

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1. Introduction

In this work we study the sensibility of the anomalous magnetic and electric dipole moments of the tau-neutrino through the processes $e^+e^- \to e^+\gamma^* e^- \to e^+\tau\bar{\nu}_\tau\nu_e$ and $e^+e^- \to e^+\gamma^*\gamma^* e^- \to e^+\nu_\tau\bar{\nu}_\tau e^-$ at a future high-energy and high-luminosity linear electron positron collider, with a center-of-mass energy in the range of 500 to 1600 GeV, such as the International Linear Collider (ILC) [1], and of 3 TeV to the Compact Linear Collider (CLIC) [2].

To illustrate our results for both processes we include a contours plot for the upper bounds of the anomalous couplings μ_{ν_τ} and d_{ν_τ} with 95% C.L. at the $\sqrt{s} = 0.5, 1.5, 3\ TeV$ with corresponding maximum luminosities for both processes. The sensitivity limits on the magnetic moment μ_{ν_τ} and the electric dipole moment d_{ν_τ} of the tau-neutrino for different values of photon virtuality, center-of-mass energy and luminosity are also calculated.

This paper is organized as follows. In Section 2, we study the dipole moments of the tau-neutrino through the processes $e^+e^- \to e^+\gamma^* e^- \to e^+\tau\bar{\nu}_\tau\nu_e$. In Section 3, we study the dipole moments of the tau-neutrino through the processes $e^+e^- \to e^+\gamma^*\gamma^* e^- \to e^+\nu_\tau\bar{\nu}_\tau e^-$. Finally, we present our results and conclusions in Section 4.

2. Dipole moments via $e^+e^- \to e^+\gamma^* e^- \to e^+\tau\bar{\nu}_\tau\nu_e$

The corresponding Feynman diagrams for the main reaction $e^+e^- \to e^+\gamma^* e^- \to e^+\tau\bar{\nu}_\tau\nu_e$, as well as for the subprocess $\gamma^* e^- \to \tau\bar{\nu}_\tau\nu_e$ which give the most important contribution to the total cross-section are shown in Figs. 1-2. From Fig. 2, the Feynman diagrams (1)-(3) correspond to the contribution of the standard model, while diagram (4) corresponds to the anomalous contribution, that is to say, for the $\gamma^* e^-$ collisions there are SM background at the tree-level so the total cross-section is proportional to $\sigma_{Tot} = \sigma_{SM} + \sigma_{Int}(\mu_{\nu_\tau}, d_{\nu_\tau}) + \sigma_{Anom}(\mu^2_{\nu_\tau}, d^2_{\nu_\tau}, \mu_{\nu_\tau} d_{\nu_\tau})$, respectively.

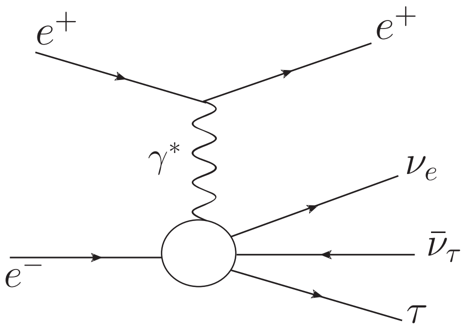

Figure 1: Schematic diagram for the process $e^+e^- \to e^+\gamma^* e^- \to e^+\tau\bar{\nu}_\tau\nu_e$.

To illustrate our results in Fig. 3 we used three center-of-mass energies $\sqrt{s} = 0.5, 1.5, 3\ TeV$ planned for the ILC and CLIC accelerators in order to get contours limits in the plane $\mu_{\nu_\tau} - d_{\nu_\tau}$ for $e^+e^- \to e^+\gamma^* e^- \to e^+\tau\bar{\nu}_\tau\nu_e$ and the planned luminosities of $\mathscr{L} = 230, 320, 590\ fb^{-1}$ and Weizsacker-Williams photon virtuality $Q^2 = 64\ GeV^2$.

As an indicator of the order of magnitude, in Table 1 we present the bounds obtained on the μ_{ν_τ} magnetic moment and d_{ν_τ} electric dipole moment for $Q^2 = 64\ GeV^2$, $\sqrt{s} = 0.5, 1.5, 3\ TeV$ and

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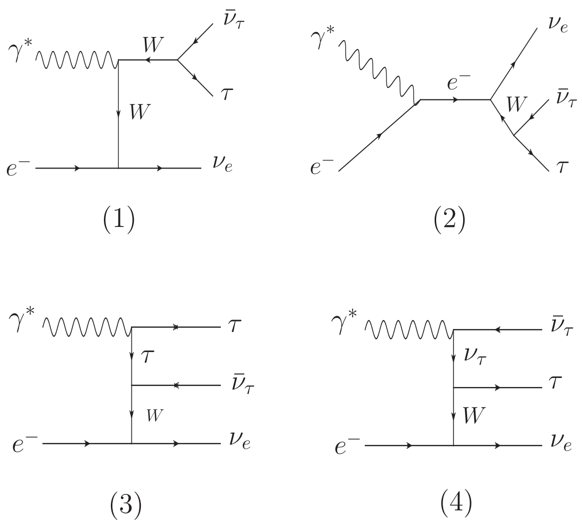

Figure 2: The Feynman diagrams contributing to the subprocess $\gamma^* e^- \to \tau \bar{\nu}_\tau \nu_e$.

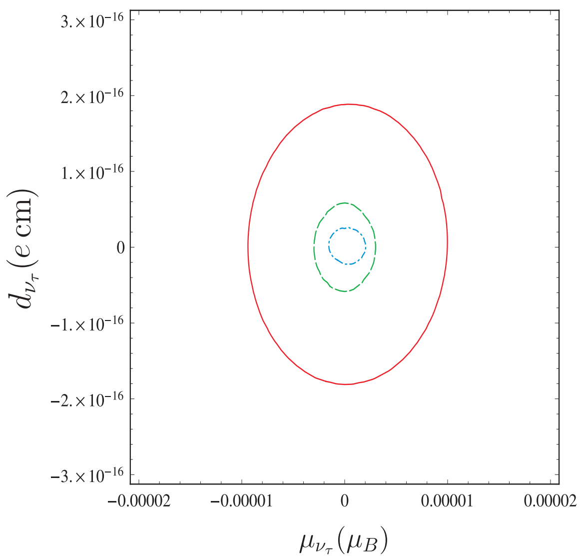

Figure 3: Limits contours at the 95% *C.L.* in the $\mu_{\nu_\tau} - d_{\nu_\tau}$ plane for $e^+e^- \to e^+\gamma^* e^- \to e^+\tau\bar{\nu}_\tau\nu_e$.

$\mathscr{L} = 230, 320, 590\ fb^{-1}$ at 2σ and 3σ *C.L.*, respectively. We observed that the results obtained in Table 1 are competitive with those reported in the literature [3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 20, 19, 21]. For the electric dipole moment our limits compare favorably with those reported by K. Akama, *et al.* [22] $|d_{\nu_\tau}| < O(2\times 10^{-17}\ ecm)$ and R. Escribano, *et al.* [23] $|d_{\nu_\tau}| \leq 5.2\times 10^{-17}\ ecm$, 95% *C.L.*

3. Dipole moments via $e^+e^- \to e^+\gamma^*\gamma^* e^- \to e^+\nu_\tau\bar{\nu}_\tau e^-$

We study the dipole moments of the tau-neutrino via the process $e^+e^- \to e^+\gamma^*\gamma^* e^- \to e^+\nu_\tau\bar{\nu}_\tau e^-$

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$\sqrt{s} = 0.5,\ 1.5,\ 3\ TeV$, $\mathscr{L} = 230, 320, 590\ fb^{-1}$		
C. L.	$\lvert\mu_{\nu_\tau}(\mu_B)\rvert$	$\lvert d_{\nu_\tau}(ecm)\rvert$
2σ	$(8.22,\ 2.88,\ 1.32)\times 10^{-6}$	$(15.8,\ 5.56,\ 2.54)\times 10^{-17}$
3σ	$(8.97,\ 3.14,\ 1.44)\times 10^{-6}$	$(17.3,\ 6.06,\ 2.78)\times 10^{-17}$

Table 1: Bounds on the μ_{ν_τ} magnetic moment and d_{ν_τ} electric dipole moment for the process $e^+e^- \to e^+\gamma^* e^- \to e^+\tau\bar{\nu}_\tau\nu_e$ for $Q^2 = 64\ GeV^2$, $\sqrt{s} = 0.5, 1.5, 3\ TeV$ and $\mathscr{L} = 230, 320, 590\ fb^{-1}$ at 2σ and 3σ C. L.

for energies expected at the ILC and CLIC [1, 2]. The corresponding Feynman diagrams for the subprocess $\gamma^*\gamma^* \to \nu_\tau\bar{\nu}_\tau$ which give the most important contribution to the total cross-section are shown in Figs. 4 and 5. In this case, the total cross-section of the subprocess depends only on the diagrams (1) and (2) with anomalous couplings, and there is no contribution at tree level of the standard model, which is to say $\sigma_{Tot} = \sigma(\mu^4_{\nu_\tau}, d^4_{\nu_\tau}, \mu^3_{\nu_\tau} d_{\nu_\tau}, \mu^2_{\nu_\tau} d^2_{\nu_\tau}, \mu_{\nu_\tau} d^3_{\nu_\tau})$.

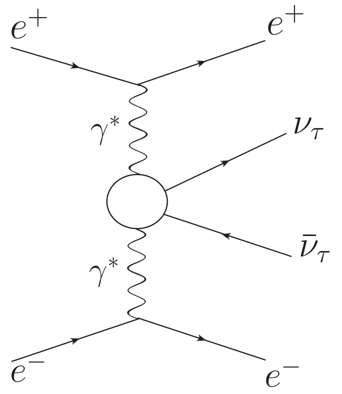

Figure 4: Schematic diagram for the process $e^+e^- \to e^+\gamma^*\gamma^* e^- \to e^+\nu_\tau\bar{\nu}_\tau e^-$.

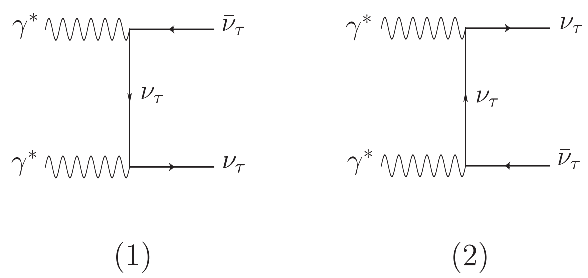

Figure 5: The Feynman diagrams contributing to the subprocess $\gamma^*\gamma^* \to \nu_\tau\bar{\nu}_\tau$.

In Fig. 6 we summarize the respective limit contours for the dipole moments in the $\mu_{\nu_\tau} - d_{\nu_\tau}$ plane for $e^+e^- \to e^+\gamma^*\gamma^* e^- \to e^+\nu_\tau\bar{\nu}_\tau e^-$. Starting from the top, the curves are for $\sqrt{s} = 0.5$ TeV and $\mathscr{L} = 230\ fb^{-1}$; $\sqrt{s} = 1.5\ TeV$ and $\mathscr{L} = 320\ fb^{-1}$; $\sqrt{s} = 3\ TeV$ and $\mathscr{L} = 590\ fb^{-1}$, respectively. We have used $Q^2 = 64\ GeV^2$.

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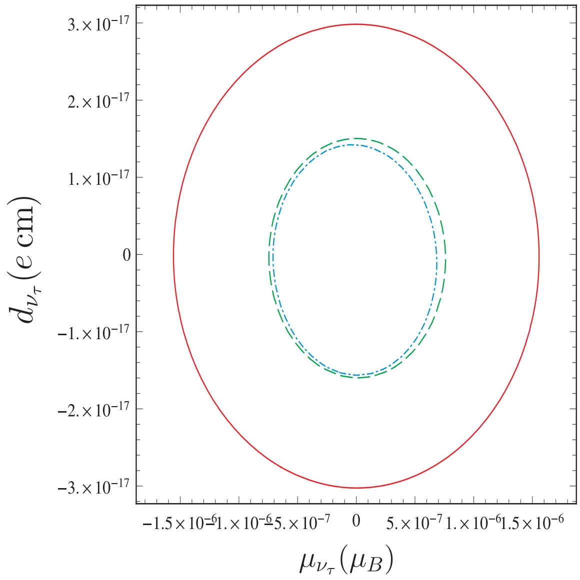

Figure 6: Limits contours at the 95% $C.L.$ in the $\mu_{\nu_\tau} - d_{\nu_\tau}$ plane for $e^+e^- \to e^+\gamma^*\gamma^*e^- \to e^+\nu_\tau\bar{\nu}_\tau e^-$.

In Table 2 we present the bounds obtained on the μ_{ν_τ} magnetic moment and d_{ν_τ} electric dipole moment for $\sqrt{s} = 0.5, 1.5, 3\ TeV$, $Q^2 = 64\ \ GeV^2$ and $\mathscr{L} = 230, 320, 590\ fb^{-1}$ at 2σ and 3σ. We observed that the results obtained in Table 2 improve the bounds reported in the literature [3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 20, 19, 21].

$\sqrt{s} = 0.5,\ 1.5,\ 3\ TeV$, $\mathscr{L} = 230, 320, 590\ fb^{-1}$		
C. L.	$\lvert\mu_{\nu_\tau}(\mu_B)\rvert$	$\lvert d_{\nu_\tau}(ecm)\rvert$
2σ	$(9.90,\ 5.20,\ 3.10)\times 10^{-7}$	$(1.91,\ 1.00)\times 10^{-17},\ 5.98\times 10^{-18}$
3σ	$(10.60,\ 5.54,\ 3.40)\times 10^{-7}$	$(2.04,\ 1.07)\times 10^{-17},\ 6.56\times 10^{-18}$

Table 2: Bounds on the μ_{ν_τ} magnetic moment and d_{ν_τ} electric dipole moment for the process $e^+e^- \to e^+\gamma^*\gamma^*e^- \to e^+\nu_\tau\bar{\nu}_\tau e^-$ for $Q^2 = 64\ GeV^2$, $\sqrt{s} = 0.5, 1.5, 3\ TeV$ and $\mathscr{L} = 230, 320, 590\ fb^{-1}$ at 2σ and 3σ C. L.

4. Conclusions

In conclusion, we have found that the processes $e^+e^- \to e^+\gamma^*e^- \to e^+\tau\bar{\nu}_\tau\nu_e$ and $e^+e^- \to e^+\gamma^*\gamma^*e^- \to e^+\nu_\tau\bar{\nu}_\tau e^-$ in the γ^*e^- and $\gamma^*\gamma^*$ collision modes at the high energies and luminosities expected at the ILC and CLIC colliders can be used to probe for bounds on the magnetic moment μ_{ν_τ} and electric dipole moment d_{ν_τ} of the tau-neutrino. In particular, we can appreciate that for integrated luminosities of $590\ fb^{-1}$ and center-of-mass energies of $3\ TeV$, we derive 95% $C.L.$ limits on the dipole moments: $\mu_{\nu_\tau} \leq 1.44\times 10^{-6}\mu_B$ and $d_{\nu_\tau} \leq 2.78\times 10^{-17}\ e\,cm$ for the process $e^+e^- \to e^+\gamma^*e^- \to e^+\tau\bar{\nu}_\tau\nu_e$ and of $\mu_{\nu_\tau} \leq 3.4\times 10^{-7}\mu_B$ and $d_{\nu_\tau} \leq 6.56\times 10^{-18}\ e\,cm$ for $e^+e^- \to e^+\gamma^*\gamma^*e^- \to e^+\nu_\tau\bar{\nu}_\tau e^-$, better than those reported in the literature.

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